

UNCLASSIFIED

AD NUMBER

ADB232051

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors;
Administrative/Operational Use; 23 JUL 1943.
Other requests shall be referred to Office of Scientific Research and Development, Washington, DC 20301.

AUTHORITY

OTS index dtd Jun 1947

THIS PAGE IS UNCLASSIFIED

Reproduced by
AIR DOCUMENTS DIVISION



HEADQUARTERS AIR MATERIEL COMMAND

WRIGHT FIELD, DAYTON, OHIO

Reproduced by

The
U.S. GOVERNMENT

IS ABSOLVED

FROM ANY LITIGATION WHICH MAY

ENSUE FROM THE CONTRACTORS IN -

FRINGING ON THE FOREIGN PATENT

RIGHTS WHICH MAY BE INVOLVED.

REEL - C

1 1 7 7

A.T.I.

2 7 7 1 0

601.131

281

NATIONAL DEFENSE RESEARCH COMMITTEE
of
OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
WAR METALLURGY DIVISION

Declassified to
SPR

Progress Report

on

DEVELOPMENT OF ARMOR WELDING ELECTRODES:
RELATION OF THE COMPOSITION OF AUSTENITIC (20 Cr-10 Ni)
ELECTRODES TO THE PHYSICAL AND BALLISTIC
PROPERTIES OF ARMOR WELDMENTS
(OD-36-2)

by

A. L. FEILD, F. K. BLOOM, and G. E. LINNERT
RUSTLESS IRON AND STEEL CORPORATION

OSRD No. 1636

Serial No. M-101

Copy No. 175

July 20, 1943

~~This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, 50 U.S.C. 31 and 32. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.~~

July 20, 1943

To: Dr. James B. Conant, Chairman
National Defense Research Committee of the
Office of Scientific Research and Development

From: War Metallurgy Division (Div. 18), NDRC

Subject: Progress Report on "Development of Armor Welding Electrodes:
Relation of the Composition of Austenitic (20 CR-10 Ni)
Electrodes to the Physical and Ballistic Properties of
Armor Weldments" (OD-36-2)

The attached progress report submitted by A. L. Feild, Technical Representative on NDRC Research Project NRC-2R, has been approved by representatives of the War Metallurgy Committee in charge of the work. This report covers investigations on restrained double bevel armor joints welded with electrodes having variations in manganese content combined with variations in molybdenum content. Testing included determination of sensitivity to center root bead cracking, interface cracking, as well as X-ray, macro etch, and metallographic examination. Physical and ballistic properties were determined by tensile tests and a special explosion test.

This project is financed by Rustless Iron and Steel Corporation and is being carried out as a correlation project under the supervision and direction of the War Metallurgy Committee.

Acceptance as a satisfactory progress report is recommended.

Respectfully submitted,



Clyde Williams, Chief
War Metallurgy Division, NDRC

Enclosure ,

PREFACE

This report is pertinent to the problems designated by the War Department Liaison Officer with NDRC as OD-36-2, and to the project designated by the War Metallurgy Committee as NDRC Research Project NRC-2R.

The distribution of this report is as follows:

Copies No. 1 through 28 - Dr. Irvin Stewart, Executive Secretary, OSRD
Copy No. 29 - Clyde Williams, Chief, War Metallurgy Division (Div. 18), NDRC
and Chairman, War Metallurgy Committee
Copy No. 30 - Office of the Executive Secretary, War Metallurgy Committee
Copy No. 31 - V. H. Schnee, Chairman, Products Research Division,
War Metallurgy Committee
Copy No. 32 - R. C. Tolman, Chairman, Sub-Committee for Division 18, NDRC
Copy No. 33 - Roger Adams, Member, Sub-Committee for Division 18, NDRC
Copy No. 34 - W. F. Davidson, Staff Aide for Division 18, NDRC
Copies No. 35 through 37 - Major General C. C. Williams,
War Department Liaison Officer with NDRC
Copy No. 38 - Commanding General, Watertown Arsenal
Attn: Director of Laboratories, Project Liaison Officer
Copy No. 39 - G. S. Mikhailapov, Research Supervisor,
NDRC Research Project NRC-2R
Copy No. 40 - Lt. Comdr. J. C. Blake, Project Liaison Officer
Copy No. 41 - A. L. Feild, Technical Representative,
NDRC Research Project NRC-2R

To the Following Members of the Subcommittee on Welding of Armor,
Ferrous Metallurgical Advisory Board, Ordnance Department

Service Representatives

Copy No. 42 - Commanding General, Army Air Forces, Wright Field
Attn: Major C. McInnes, Ordnance Section
Copy No. 43 - Commanding General, Army Air Forces, Wright Field
Attn: Captain R. H. Mott, Experimental Engineering Section
Copy No. 44 - Commanding General, Army Air Forces, Wright Field
Attn: Lt. R. E. Bowman, Experimental Engineering Section
Copy No. 45 - Commanding General, Army Air Forces, Wright Field
Attn: B. C. White, Experimental Engineering Section
Copy No. 46 - Commanding General, Aberdeen Proving Ground
Attn: Lt. W. C. Fless, Proving Center
Copy No. 39 - Commanding General, Watertown Arsenal
Attn: Colonel H. H. Zornig, Director of Laboratories
Copy No. 47 - Commanding General, Watertown Arsenal
Attn: W. L. Warner, Laboratory
Copy No. 48 - Deputy Chief of Ordnance, Tank Automotive Center
Attn: Major D. C. Pippel, Engineering Branch

Copy No. 49 - Deputy Chief of Ordnance, Tank Automotive Center
 Attn: Major J. V. Coombe, Engineering Branch
 Copy No. 50 - Deputy Chief of Ordnance, Tank Automotive Center
 Attn: Lt. J. F. Randall, Engineering Branch
 Copy No. 51 - Deputy Chief of Ordnance, Tank Automotive Center
 Attn: Lt. A. F. Boucher, Engineering Branch
 Copy No. 52 - District Chief, Chicago Ordnance District
 Copy No. 53 - District Chief, Cincinnati Ordnance District
 Copy No. 54 - District Chief, Cleveland Ordnance District
 Copy No. 55 - District Chief, Detroit Ordnance District
 Copy No. 56 - District Chief, Philadelphia Ordnance District
 Copy No. 57 - District Chief, Pittsburgh Ordnance District
 Copy No. 58 - District Chief, Rochester Ordnance District
 Copy No. 39 - National Research Council, War Metallurgy Committee
 Attn: G. S. Mikhalapov
 Copy No. 59 - National Research Council, War Metallurgy Committee
 Attn: J. H. Humberstone
 Copy No. 40 - Navy Department, Bureau of Ships
 Attn: Lt. Comdr. J. C. Blake
 Copy No. 60 - Navy Department, Philadelphia Navy Yard
 Attn: Lt. Comdr. O. R. Sutherland
 Copy No. 61 - Navy Department, Naval Gun Factory
 Attn: Lt. Comdr. W. S. Newton
 Copy No. 62 - Navy Department, Bureau of Ships
 Attn: A. G. Bissell
 Copy No. 63 - Office, Chief of Ordnance, Technical Division
 Attn: Colonel G. E. Knable
 Copy No. 64 - Office, Chief of Ordnance, Technical Division
 Attn: Mr. E. L. Hollady
 Copy No. 65 - Office, Chief of Ordnance, Technical Division
 Attn: Captain G. E. Drewes
 Copy No. 66 - Headquarters, Army Service Forces
 Attn: Chief, Conservation Branch, Production Division
 Copy No. 67 - War Production Board, General Industrial Equipment Division
 Attn: J. H. Cooper, Chief, Resistance Welding Section

Industrial Representatives

Copy No. 68 - A. L. Abbott, Diebold Safe & Lock Company
 Copy No. 69 - M. J. Barry, Joslyn Manufacturing & Supply Company
 Copy No. 70 - G. C. Beishline, American Car Foundry Company
 Copy No. 71 - L. C. Bibber, Carnegie-Illinois Steel Corporation
 Copy No. 72 - E. Biederman, Fisher Tank Division, General Motors Corporation
 Copy No. 73 - N. J. Blake, Chrysler Tank Arsenal
 Copy No. 74 - K. Blanchard, A. O. Smith Corporation
 Copy No. 75 - W. Boese, Pullman-Standard Car & Manufacturing Company
 Copy No. 76 - E. J. Brady, Alloy Rods Company
 Copy No. 77 - S. A. Braley, Pittsburgh Steel Company

Copy No. 78 - B. J. Brugge, Lincoln Electric Company
Copy No. 79 - C. H. Burgston, Deere & Company
Copy No. 80 - J. J. Burns, Plymouth Motor Car Company
Copy No. 81 - C. K. Carter, Pressed Steel Car Company, Inc.
Copy No. 82 - J. O. Cavanagh, Hollup Corporation
Copy No. 83 - T. P. Champion, Champion Rivet Company
Copy No. 84 - J. J. Chyle, A. O. Smith Corporation
Copy No. 85 - Roger Clark, General Electric Company
Copy No. 86 - C. C. Cross, Plymouth Motor Car Company
Copy No. 87 - L. A. Danse, Cadillac Motor Car Div., General Motors Corporation
Copy No. 88 - J. H. Deppeler, Metal & Thermit Corporation
Copy No. 89 - J. M. Diebold, Yellow Truck & Coach Manufacturing Company
Copy No. 90 - F. Dobbs, New York Air Brake Company
Copy No. 91 - E. C. Dodt, Chrysler Tank Arsenal
Copy No. 92 - L. H. Dunham, American Steel & Wire Company
Copy No. 93 - W. P. Eddy, Jr., Yellow Truck & Coach Manufacturing Company
Copy No. 94 - G. A. Ellinger, National Bureau of Standards
Copy No. 95 - D. S. Elliott, Glenn L. Martin Company
Copy No. 96 - W. V. Emery, Ilco Ordnance Corporation
Copy No. 97 - C. D. Evans, International Harvester Company
Copy No. 98 - H. N. Swertz, Arcos Corporation
Copy No. 99 - J. K. Findley, Allegheny Ludlum Steel Company
Copy No. 100- C. V. Foerster, Coast Metals, Inc.
Copy No. 101- L. S. Fry, Joslyn Manufacturing & Supply Company
Copy No. 102- F. Garratt, Universal-Cyclops Steel Corporation
Copy No. 103- D. H. E. Genter, Standard Steel Spring Company
Copy No. 104- R. A. Gezelius, General Steel Castings Corporation
Copy No. 105- R. T. Gillette, General Electric Company
Copy No. 106- J. A. Goodford, Crucible Steel Company of America
Copy No. 107- P. B. Greenawald, Carpenter Steel Company
Copy No. 108- E. S. Groves, New York Air Brake Company
Copy No. 109- W. C. Hamilton, American Steel Foundries
Copy No. 110- C. Hart, Heil Company
Copy No. 111- P. Hickman, Richmond Engineering Company
Copy No. 112- R. Housel, Fisher Tank Division, General Motors Corporation
Copy No. 113- H. L. Ingram, Jr., Air Reduction Sales Company
Copy No. 114- C. E. Jackson, Naval Research Laboratory
Copy No. 115- Colonel G. F. Jenks, Taylor-Whitfield Corporation
Copy No. 116- C. H. Jennings, Westinghouse Electric & Manufacturing Company
Copy No. 117- J. W. Juppenlatz, Lebanon Steel Foundry
Copy No. 118- C. F. Kaunitz, National Electric Welding Machine Company
Copy No. 119- J. M. Keir, Linde Air Products Company
Copy No. 120- F. C. Knight, Una Welding, Inc.
Copy No. 121- R. S. Komarnitsky, Standard Steel Spring Company
Copy No. 122- J. K. Kumer, Jr., Allegheny Ludlum Steel Company
Copy No. 123- C. B. Lansing, Ilco Ordnance Corporation
Copy No. 124- W. B. Libert, Continental Roll & Steel Foundry Company
Copy No. 125- T. Lichtenwalter, Republic Steel Corporation
Copy No. 126- R. E. Long, Hollup Corporation

Copy No. 127 - E. O. Mann, Chevrolet Motor Company
Copy No. 128 - D. L. Mathias, Metal & Thermit Corporation
Copy No. 129 - G. A. Maurath, Sr., Maurath, Inc.
Copy No. 130 - C. G. Merritt, Crucible Steel Company of America
Copy No. 131 - A. F. Meyer, Heil Company
Copy No. 132 - J. J. Miller, Reo Motor, Inc.
Copy No. 133 - J. W. Miller, Reid-Avery Company
Copy No. 134 - W. B. Miller, Linde Air Products Company
Copy No. 135 - T. P. Moran, Ternstedt Division, General Motors Corporation
Copy No. 136 - J. K. McDowell, Rock Island Arsenal
Copy No. 137 - M. Nelles, Lockheed Aircraft Corporation
Copy No. 138 - R. P. Nick, Champion Rivet Company
Copy No. 139 - C. F. Nixon, Ternstedt Division, General Motors Corporation
Copy No. 140 - H. E. North, Douglas Aircraft Company, Inc.
Copy No. 141 - W. C. Osha, American Car & Foundry Company
Copy No. 142 - H. D. Phillips, Lebanon Steel Foundry
Copy No. 143 - W. H. Pierson, Briggs Manufacturing Company
Copy No. 144 - A. J. Raymo, Baldwin Locomotive Works
Copy No. 145 - W. G. Rinehart, Page Steel & Wire
Copy No. 146 - M. H. Rutishauser, Harnischfeger Corporation
Copy No. 147 - M. G. Sedam, Harnischfeger Corporation
Copy No. 148 - O. B. Schultz, Lima Locomotive Works, Inc.
Copy No. 149 - R. Sibley, Henry Disston & Sons, Inc.
Copy No. 150 - J. E. Skinner, Page Steel & Wire
Copy No. 151 - B. J. Smith, Marmon-Herrington Company, Inc.
Copy No. 152 - W. A. Smith, Lima Locomotive Works, Inc.
Copy No. 153 - W. E. Smith, Midland Steel Products Company
Copy No. 154 - J. R. Stitt, Ohio State University
Copy No. 155 - F. R. Strate, Arcrods Corporation
Copy No. 156 - H. S. Swan, American Locomotive Company
Copy No. 157 - C. A. Taylor, Lincoln Electric Company
Copy No. 158 - R. D. Thomas, Jr., Arcos Corporation
Copy No. 159 - B. J. Trautman, Pullman-Standard Car & Manufacturing Company
Copy No. 160 - M. J. Vandreser, McKay Company
Copy No. 161 - G. Vennerholm, Ford Motor Company
Copy No. 162 - F. C. Whitmer, Maurath, Inc.
Copy No. 163 - V. W. Whitmer, Republic Steel Corporation
Copy No. 164 - P. R. Wray, Carnegie-Illinois Steel Corporation
Copy No. 165 -
Copy No. 166 -
Copy No. 167 -
Copy No. 168 -
Copy No. 169 -
Copy No. 170 -
Copy No. 171 -
Copy No. 172 -
Copy No. 173 -
Copy No. 174 -
Copy No. 175 -

Copy No. 176 -
Copy No. 177 -
Copy No. 178 -
Copy No. 179 -
Copy No. 180 -
Copy No. 181 -
Copy No. 182 -
Copy No. 183 -
Copy No. 184 -
Copy No. 185 -
Copy No. 186 -
Copy No. 187 -
Copy No. 188 -
Copy No. 189 -
Copy No. 190 -
Copy No. 191 -
Copy No. 192 -
Copy No. 193 -
Copy No. 194 -
Copy No. 195 -
Copy No. 196 -
Copy No. 197 -
Copy No. 198 -
Copy No. 199 -
Copy No. 200 -

Total number of copies - 200

NATIONAL DEFENSE RESEARCH COMMITTEE

N. R. C. Project #2

PROGRESS REPORT

on

Relation of the Composition of Austenitic (20 Cr-10 Ni) Electrodes to
the Physical and Ballistic Properties of Armor Weldments.

I. The Effect of Variations in Manganese and Molybdenum Contents.

From: Rustless Iron and Steel Corporation-Research Laboratory.

Report by: A. L. Feild, F. K. Bloom and G. E. Linnert

Date: June 15, 1943.

* * * * *

ACKNOWLEDGEMENTS

The work described in this report, prepared under the supervision of A. L. Foild, Official Investigator, was largely carried out at the Research Laboratory of the Rustless Iron and Steel Corporation by F. K. Bloom and G. E. Linnert with the full time collaboration of W. H. Donoho. L. F. Weitzenkorn and H. Tanczyn assisted in the preparation of the induction heats and experimental core wire. M. Clogg, Jr., G. N. Geller and Mary S. Hatter collaborated on microhardness and microscopic studies as well as in the preparation of photographs.

R. L. Henry of the Physics Department of Johns Hopkins University conducted the X-ray examination of the test plates. Dr. W. O. Snelling, Director of Research, and his associates carried out the explosion tests at the Trojan Powder Company in Allentown, Pennsylvania.

G. S. Mikhalapov, Supervisor of Welding Research, assisted in preparing the outline for the original project and offered many helpful suggestions during the investigation.

* * * * *

TABLE OF CONTENTS

	<u>Page Number</u>
Abstract	
Summary	
Introduction	1
Materials Used and Procedure	3
1) Preparation of Experimental Electrodes	3
2) Welding of Restrained Joints	3
a) Preparation of Test Plates	3
b) Determination of Sensitivity to Root Cracking	3
c) Observations During Completion of Test Welds Interface Cracking	4
3) Examination of Welded Joints	4
a) X-ray Examination	5
b) Macro Etch Examination	5
c) Tensile Tests	5
d) Metallographic Examination and Microhardness Survey	5
e) Ballistic Properties by Explosion Testing	6
4) Examination of Explosion Tested Samples	6
Discussion	7
Future Work	10
Appendix I - Table I - Analysis of Core Wire and Weld Metal	App. I - 1
Table II - Sensitivity to Root Cracking	App. I - 2
Table III - Frequency of Interface Cracking	App. I - 3
Table IV - Tensile Test Data	App. I - 4
Table V - Explosion Test Data	App. I - 5
Appendix II - Drawings, Photographs and Photomicrographs.	
Figures 1 to 18, inclusive	App. II 1 to 13

ABSTRACT

Restrained double bevel armor joints were welded with 20-10 electrodes having variations in manganese content of 1.5, 2.0 and 4.3% combined with variations in molybdenum content of 0.0, 1.5 and 3.0%. A comparison was also made between molybdenum added through the electrode coating and through the core wire and between an experimental induction melted and a commercial electric-arc furnace heat. Testing included determination of sensitivity to center root bead cracking, interface cracking, as well as X-ray, macro etch and metallographic examination. Physical and ballistic properties were determined by tensile tests and a special explosion test. Significant features disclosed were:

- (1) Variations in manganese and molybdenum content
 - a) affected sensitivity to root cracking,
 - b) possibly affected susceptibility to interface cracking,
 - c) appeared related to tendency to transformation to martensitic structures on heavy dilution.

High manganese contents combined with the use of some molybdenum are believed to represent the best combination.

- (2) Ballistic properties could not be related to composition. The initiation and propagation, in the armor, of cracks produced in the ballistic test may explain this and suggest that the ballistic values secured in these tests were associated more directly to the properties of the armor than to those of the weld metal.
- (3) No indication could be found that molybdenum added through the electrode coating produced any different properties than when added through the core wire.
- (4) Induction melted experimental heats gave comparable results to a commercial electric-arc furnace heat.

* * * * *

SUMMARY

The preliminary work undertaken in this investigation must be verified by similar tests with commercially prepared electrodes and with several other types of armor as well as with conventional ballistic tests, before any final conclusions can be drawn. Nevertheless, several features believed to be significant have been revealed in these tests which have been summarized below. The similarity in results obtained with a commercially melted heat when compared with an induction melted heat of similar analysis justifies the belief that these observations are not limited to induction melted material alone.

- (1) The composition of 20 Cr-10 Ni type electrodes appears to govern the ease with which crack free deposits can be made in the root pass of restrained double bevel armor joints. Additions of molybdenum appear desirable. Manganese alone is not helpful.
- (2) Some evidence was found that interface cracking in the root pass may also be related to electrode composition. The indication is again that molybdenum is helpful in overcoming this defect. The complicating factor of heavy root deposits required with compositions without molybdenum however prevented drawing any direct comparisons. Deposits from the lowest alloy containing electrode (1.5 Mn-0.0 Mo) used in the investigation were unusually susceptible to this defect.
- (3) The tendency for weld deposits to transform to hard brittle martensitic structures in passes where heavy dilution is present appears to be related to the total alloy content. Electrodes, where the sum of the manganese plus molybdenum content was less than about 4.0%, were found to be transformed in the shoulder passes.
- (4) No indication could be found that molybdenum added indirectly to the deposit through the flux produced any different properties than when added directly through the core wire.
- (5) No appreciable variation in the shock resistance of the specimens exposed to the explosive tests was found to exist with variations of the manganese-molybdenum content of the weld metal.
- (6) The failure to find any direct correlation between electrode composition and ballistic strength values secured in the explosion test may be traceable to the apparent tendency for fractures to originate and propagate largely on the armor side of the weld interface. This preliminary evidence that ballistic properties may be related more to the properties of the armor than of the weld recommends itself for further investigation.
- (7) From the standpoint of the ease of welding restrained armor joints, electrodes containing sufficiently high manganese contents to insure freedom from dilution transformation and also with molybdenum contents adequate to minimize center root cracking are believed to represent the most desirable combination.

PROGRESS REPORTonRelation of the Composition of Austenitic (20 Cr-10 Ni) Electrodes to
the Physical and Ballistic Properties of Armor Weldments.I. The Effect of Variations in Manganese and Molybdenum Contents.INTRODUCTION

The general aim of this project was to study the effect of variations in the composition of austenitic 20 Cr-10 Ni type electrodes on the properties of restrained armor weldments.

Two types of 20-10 electrodes have been used in tank-armor fabrication; one modified by additions of manganese, one by additions of molybdenum. Various combinations of the two elements have also been considered. Very little fundamental information has been available, however, to indicate what effect variations in the per cent of these elements have on weld properties. This first progress report describes an investigation undertaken to provide such data as could be secured by carefully controlled tests on a laboratory scale.

The specific aims of this first investigation were to:

- (1) Determine the effect of variations in manganese and molybdenum content on the welding properties, particularly sensitivity to root cracking, the physical properties and microstructure of restrained welds in armor.
- (2) Estimate the effect of variations in the per cent of these elements in the weld deposit on the ballistic properties by means of a special explosion test.
- (3) Compare the effect of molybdenum alloyed in the weld deposit through the core wire with molybdenum added through the electrode coating.

Various steps taken in this investigation included:

- (1) Preparation of electrodes from nine experimental induction melted heats and one commercial electric-arc furnace heat. The heats were of 20 Cr-10 Ni type representing seven different levels of manganese and molybdenum contents. The approximate analyses are listed on the following page

Series No.	Composition Identity *	Melting Practice	C	Cr	Ni	Mn	Mo
I	1.5 Mn-0.0 Mo	Induction	.10	20.0	10.0	1.50	--
	2.0 Mn-0.0 Mo	Induction	.10	20.0	10.0	2.00	--
	2.0 Mn-0.0 Mo-E	Electric	.10	20.0	10.0	2.00	--
	4.3 Mn-0.0 Mo	Induction	.10	20.0	10.0	4.25	--
II	2.0 Mn-1.5 Mo	Induction	.10	20.0	10.0	2.00	1.50
	2.0 Mn-(1.5 Mo)	Induction	.10	20.0	10.0	2.00	(1.50)*
	2.0 Mn-(1.5 Mo)-E	Electric	.10	20.0	10.0	2.00	(1.50)*
	2.0 Mn-3.0 Mo	Induction	.10	20.0	10.0	2.00	3.00
III	4.3 Mn-1.5 Mo	Induction	.10	20.0	10.0	4.25	1.50
	4.3 Mn-(1.5 Mo)	Induction	.10	20.0	10.0	4.25	(1.50)*
	4.3 Mn-3.0 Mo	Induction	.10	20.0	10.0	4.25	3.00

* Throughout the balance of the report the various compositions will be identified by the symbols shown in this table. (1.5 Mo) indicates molybdenum added through the flux; the suffix E indicates material melted commercially in the electric-arc furnace.

Series I was designed to compare the effect of three levels of manganese 1.50, 2.00 and 4.25% alone. Series II was included to compare the effect of 1.5% and 3.0% molybdenum with manganese fixed at 2.00%; Series III to compare the same levels of molybdenum with manganese fixed at 4.25%. Compositions 2.0 Mn - (1.5 Mo) and 4.3 Mn - (1.5 Mo) were included in the latter two series to compare molybdenum introduced into the weld deposit through the flux with molybdenum added through the core wire.

During the course of the investigation, a commercially melted electric-arc furnace heat of analysis similar to composition 2.0 Mn - 0.0 Mo became available and was included in Series I and Series II for comparison with the induction melted heats.

- (2) Welding of duplicate restrained joints from each composition, noting sensitivity of each type of electrode to (a) root bead cracking, and (b) interface cracking.
- (3) Examination of welded joints including:
 - a) X-ray examination of "as welded" plates
 - b) Macro etch for quality of welds
 - c) Transverse tensile properties of welds
 - d) Metallographic examination of welds and microhardness traverses
 - e) Ballistic properties by explosion testing
- (4) Examination of explosion tested samples.

1. Preparation of Experimental Electrodes

Nine, twenty-five pound experimental induction melted heats were prepared in an Ajax high frequency furnace. The small ingots (together with one billet from the commercial electric-arc furnace heat) were forged and hot rolled to rods. The hot rolled rods were annealed, pickled and cold drawn by the usual commercial methods to core wire of 1/4" and 3/16" diameter. Straightened and cut wire in 14" lengths was then flux coated in an experimental laboratory extrusion press. In all cases, a lime base flux of composition similar to those found to be employed on commercial rods of this type was used. The same formula was used throughout except for small variations in the content of ferromanganese from heat to heat necessary to maintain the level of this element the same in the weld deposit as the core wire. Ferromolybdenum was employed where it was desired to alloy molybdenum with the weld deposit.

The efficiency of the flux was gauged by conducting a complete analysis of a weld pad prepared from each lot of coated 1/4" diameter electrodes. The procedure used was similar to that now required by the Bureau of Ships Specification 4624(INF) April 1, 1943. These analyses are listed for comparison with the core wire analyses in Table I*-Appendix I.

2. Welding of Restrained Joints

2a) Preparation of Test Plate

Figure 1**-Appendix II shows the details of design and welding sequence employed in preparing the restrained joint. The intent was to secure a test plate containing a highly restrained double bevel butt weld. For additional restraint, the test plates were rigidly clamped in a heavy jig throughout the entire welding procedure and for a period thereafter of twenty-four hours. Figures 2 and 3 show, respectively, the appearance of a test plate clamped in the jig ready for welding and a final welded plate.

All test plates were torch cut and beveled to size from four, 1 1/2" thick plates of Great Lakes homogeneous heat treated armor, representing one heat of the following composition:

Heat 9-00474	C	Mn	P	S	Si	Cr	Mo	Zr
Mill Analysis	.29	.94	.018	.025	.67	.59	.18	.09

This armor was chosen because of its wide use and because it was generally believed to be somewhat more critical in its demands on the performance of the electrodes.

In all cases, the test plates were assembled with the rolling direction of the armor at right angles to the weld axis as indicated in Figure 1. After each pass across the weld, the test plate was allowed to cool to a maximum of 200°F. before proceeding.

* All tables are assembled in Appendix I.

** All drawings and photographs are assembled in Appendix II.

2b) Determination of Sensitivity to Root Cracking

Work done previous to this investigation disclosed that the 20 Cr-10 Ni composition exhibits a marked tendency to crack down the center of the first or root pass under certain conditions. Preliminary tests disclosed that the degree of cracking was apparently chiefly related to the thickness of the deposit, i.e., the thicker the root pass the less the likelihood of cracking.

Root beads of various thicknesses were deposited with several different types of electrodes and the degree of cracking noted. In each case there appeared to be a characteristic critical root thickness above which cracking no longer occurred. This observation suggested a possible method of rating each of the compositions included in the investigation for sensitivity to root cracking.

As each of the three segments across the root was deposited in each test plate, the thickness of the weld was measured and recorded together with the appearance of the bead. Figures 4, 5 and 6 illustrate the technique employed. Figures 4 and 5 show the appearance of the face and back of a root pass deposited with three, 3/16" diameter, electrodes of composition 2.0 Mn-0.0 Mo-E. Figure 6 shows the appearance of cross-sections through the three different locations indicated in Figures 4 and 5. It is of interest to note that in the root passes slightly thicker than required to prevent complete cracking, the crack appears only on the back side of the weld.

The data secured in these tests are recorded in detail in Table II. In most cases, it was possible to estimate within fairly narrow limits, the critical root thickness required for each composition. In one case, the root beads were all deposited without exhibiting cracking. Here, it is assumed, the critical root thickness was less than that deposited.

2c) Observations During Completion of Test Welds, Interface Cracking

After determining the critical root thickness, all cracked root beads were chipped out and new beads of sufficient thickness to avoid center cracking were deposited. With certain compositions no further difficulties were experienced and welding proceeded as indicated in Figure 1. However, others exhibited a marked tendency to develop cracks at the interface between the root bead and the armor. This type of crack was quite distinct in appearance and location from the center root cracks described above. They were very narrow in width and extended from as little as 1/8" to the full 8" length of the root pass. In many cases, they were detectable only by examining the junction of the weld metal and armor with a small hand magnifying glass. They occurred almost without exception in the root pass. In several cases it was necessary to weld several plates before two were secured free from this defect. Table III summarizes these experiences and indicates the frequency of interface cracking in various compositions.

3. Examination of Welded Joints

After completion of welding (See Figure 3) and removal from the restraining jig, each test plate was ground on both sides on a Blanchard Grinder to bring the top of the weld flush with surface of the armor.

After X-ray examination, the plates were sectioned by cold sawing in the manner illustrated in Figure 7. One of each of the duplicate test plates, after discarding the outer 2", provided two macro etch test specimens, two explosion test specimens, one specimen for microscopic examination and three tensile test specimens from the face, root and back of the weld. The second plate provided two macro etch specimens and three explosion test samples.

3a) X-ray Examination

The plates were radiographed at Johns Hopkins University by Mr. R. L. Henry. A 200 KV General Electric machine employing a tungsten target was used. The following exposure conditions, after trial, were applied:

Voltage	- 170 KV	Focal distance	- 64 inches
Amperage	- 10 m.a.	Film	- Eastman Type X
Filter	- filter cassette	Penetrameter	- 2%, visible
Exposure time	- 25 to 30 minutes		

3b) Macro Etch Examination

Macro etch specimens were ground flat on a 320 grit belt, etched in cold dilute aqua-regia for 1 to 3 minutes and examination at 15 X magnification for the presence of defects. Figure 8 illustrates the appearance of three typical etched specimens.

3c) Tensile Tests

Rectangular shaped tensile test specimens cut transversely across the weld, representing the face, root and back of the weld, as shown in Figure 7, were ground with a 320 grit finish to final dimensions of $9/32"$ by $1"$. Tensile tests were conducted on a 120,000# hydraulic machine. An attempt was made to maintain a constant headspeed by employing fixed valve openings in all tests. The headspeed from the yield point to breaking load was approximately $0.3"$ per minute. Per cent elongation was measured across the welds using three gauge lengths. Standard two inch gauge marks were made in the armor with the weld at the center. In addition, punch marks were made at the interface between the weld metal and armor, both at the widest point across the weld and at the narrowest point across the weld. Table IV, Appendix I contains the data secured in these tests and noted the location of the fracture of each specimen. The yield strength was determined from autographic stress-strain curves with the extensometer attached over a 2" gauge including weld metal and some armor. The offset used in calculating the values was taken as .2% of the average width of the weld metal.

It will be noted in Table IV that a number of the tensile test samples cut from the face and back of the plates were found to have broken across the weld metal in the shoulder. These fractures were brittle in appearance and resulted in generally lower per cent elongations. Rockwell hardness tests made on the samples selected for microscopic examination showed that these brittle fractures were associated with transformation of the weld metal in the shoulder pass to a hard martensitic structure. The hardness values secured on the shoulder passes are recorded with the tensile test results for comparison.

3d) Metallographic Examination and Microhardness Survey

Samples prepared from the middle of one weld of each type were examined. Photomicrographs, Figures 9 to 11, were prepared illustrating the appearance of the weld structure at a point near the center of each root bead. Microhardness traverses were made with an Eborbach tester (28.4 gm. load) across the fusion line of samples from plates representing each of the seven compositions studied. Impressions across the interface, spaced approximately .0015" apart, were made with a Standard Vickers pyramid diamond penetrator. The area tested in each case was approximately at the middle of #4 bead on the back side of the root pass. This location was chosen because as it will be seen later, it was apparently near this point that fractures originated in the explosion test. Figure 12 is a photomicrograph of this area showing the hardness impressions. The hardness values indicated are believed correct for comparison among themselves, but their relation to Standard Vickers or Brinell values has not been established.

3e) Ballistic Properties by Explosion Testing

Explosion test samples were ground flat on side, top and bottom faces in the Blanchard Grinder to the following dimensions:

Height - $1\frac{7}{16}" \pm \frac{1}{64}"$ Width - $1\frac{7}{8}" \pm \frac{1}{64}"$ Length - $8" \pm \frac{1}{4}"$

In addition to the welded test samples, samples were also prepared of similar dimensions from the virgin armor plate. One set was selected with the direction of rolling parallel to the long axis of the specimen, i.e., longitudinal; one set with the rolling direction at right angles to the long axis, or transverse.

All tests were conducted under the direction of Dr. W. O. Snelling at the Trojan Powder Company, Allentown, Pennsylvania. Details of the set-up used are shown in Figure 13.

The test samples were rested on steel blocks with the face of the weld upwards. Charges of nitrostarch in the form of 2" diameter flat discs of different gram weights were exploded on top of the weld. Varying total amounts of explosives were used on each specimen to establish the amount required to just completely break the sample. Different weights of powder were obtained by combining discs of 20, 25, 30, 35 and 50 grams. The force applied by the explosive is not believed to be linearly proportional to the weight especially with large charges. It has been pointed out that as the height of pile of explosives increases, the downward force exerted by the powder at the top of the charge diminishes rapidly. An approximate relationship between explosive charge and impact energy expressed in terms of ball-pendulum displacement as tentatively determined by Dr. Snelling (NR C-25 Project - Explosive Tests) is attached (Figure 14).

The charges applied, the angle of bend and the appearance of the tested samples are recorded in Table V. Figure 15 shows the appearance of a typical set of specimens after testing.

4. Examination of Explosion Tested Samples

Samples which were partially cracked externally by the explosive charge as well as those which showed no external cracks were sectioned transversely through the center of the weld and subjected to metallographic examination to establish the origin and mode of fracture from the ballistic impact. Several were found containing only internal cracks varying from microscopic dimensions up to large fissures extending almost to the surface as noted in Table V. Figures 16, 17 and 18 illustrate the initiation of the cracks and the mode of progression in typical samples.

DISCUSSION1. Preparation of Electrodes

- (a) The analyses of the induction melted heats and weld deposits fell within reasonably narrow ranges. Small variations in carbon, phosphorus, sulphur, silicon, chromium and nickel contents present throughout the series were not considered to have influenced the comparison of the effect of variations in manganese and molybdenum contents. The chromium to nickel ratios of all heats fell within the range of 2.01:1.00 to 2.06:1.00.

2. Welding of Restrained Joints(a) Sensitivity to Root Bead Cracking

- (1) The effect of molybdenum in reducing the thickness of the root pass required to prevent center cracks is clearly shown in comparing the data for Series I heats without molybdenum with Series II and III heats containing 1.5% and 3.0% of this element.
- (2) Variations in manganese either without molybdenum present or with 1.5% or 3.0% of this element caused no marked trend in the results; if anything, Series II heats with a level of 2.0% Mn were slightly better than Series III with a level of 4.3% Mn.
- (3) Increasing the molybdenum from 1.5% to 3.0% showed no marked additional benefit nor was there any difference apparent between adding this element through the core wire or through the flux.
- (4) The results secured on induction melted heats compare closely with those obtained from the commercial electric-arc furnace heat.

(b) Susceptibility to Interface Cracking

- (1) Series I heats with increasing manganese and no molybdenum were susceptible to the development of interface cracks.
- (2) Composition 1.5 Mn-0.0 Mo in this series produced frequent interface cracking which was only slightly alleviated by preheating the test plates before welding.
- (3) With increasing manganese content up to 4.3%, but with no molybdenum, this defect was still present but in a lesser degree.
- (4) Welds from compositions with 2.0 and 4.3% manganese and 1.5 and 3.0% molybdenum appeared relatively free from this defect.
- (5) Difficulties experienced with Series I heats appeared to coincide with the much heavier root deposits required to prevent center cracking. Such heavy beads were more prone to results in incomplete coverage of the root joints in the back of the pass introducing, in some cases, a notch effect. This notch condition, however, was not wholly responsible for interface cracking since the defect occurred in several instances even with satisfactory root joint coverage.

3. Examination of Welded Joints

(a) X-ray Examination

Examination of the radiographs indicated that all plates were sound, free from porosity, large slag inclusions or cracks. It is of interest to note that the small interface crack later discovered in one end of a plate welded with the 2.0 Mn-0.0 Mo-E rod was not disclosed under the particular conditions of this test.

(b) Macro Etch Tests

In all cases except one, the macro etched samples disclosed no defects of significance. One plate welded with rod 2.0 Mn-0.0 Mo-E possessed a small interface crack in the root pass. This crack was later found to have progressed about 3/4 of an inch into the tensile test specimens out adjacent to the macro etch sample, but is not believed to have extended beyond this point.

(c) Transverse Tensile Tests

- (1) Tensile and yield strength values of root samples are generally higher and elongation values lower than those of samples from the face and back, probably because of greater dilution of the weld metal in these areas.
- (2) No consistent trends are discernable between tensile and yield strength values with variations in manganese or molybdenum content, different methods of introducing the latter element or between induction and electric-furnace heats. Some indication is present that the welds containing the highest manganese and molybdenum contents possessed slightly higher values.
- (3) Comparison of elongation values with variations in composition is largely voided by the erratic and generally low values obtained where face and back samples fractured through shoulder passes. Even excluding these values no clear trends seem to be present.
- (4) The presence of partial interface crack in samples from composition 2.0 Mn-0.0 Mo-E sharply reduced the tensile and elongation values.
- (5) The tendency of some compositions to transform to martensite in the highly diluted shoulder passes appears to be related to the total alloy content of the electrodes. It will be noted in Table IV that those compositions possessing over approximately 4.0% total manganese plus molybdenum possessed relatively soft shoulders while those having less than this amount were either partially or completely hardened.

(d) Microstructure and Microhardness Traverses

- (1) Microstructures in the root pass were similar in all samples, consisting of an austenitic matrix with delta ferrite containing carbides dispersed throughout.
- (2) The amount of the delta ferrite constituent varied over wide limits throughout the weld and even within the same bead. It was clear, how-

ever, that the total amount of this constituent was related to the composition. Increasing molybdenum content increased the amount of this constituent. Increasing manganese content decreased the amount. On a percentage basis molybdenum appeared to be more effective in increasing delta ferrite than manganese was in decreasing the amount of this constituent. Some inconsistencies in this rule which may appear to be present in the photomicrographs are largely traceable to the difficulty of selecting a field representative of the average structure of the weld. In addition, small variations in chromium-nickel ratio and carbon content are known to affect the per cent of this phase and their effect should be borne in mind.

- (3) Microstructures at the weld interface presented no consistent picture, but varied widely in the same sample at various locations in the weld. For this reason the structures shown in the photomicrograph of this area should not be interpreted as representative of the entire interface structure throughout the samples. Attempts to correlate variations in these structures with variations in the composition have so far failed.
- (4) One consistent feature in all cases was the presence of a narrow hard band at the interface about .0015 inches in width as shown by the microhardness values. In this band hardnesses were found ranging from 302 V.P.N. to the highest value of 712 V.P.N. found in the weld prepared from composition 1.5 Mn-0.0 Mo.

(e) Ballistic Properties by Explosion Testing

- (1) Some variations were found in the charges required to break the various welds, but no clear cut trend could be found between these values nor the angle at fracture with variations in manganese or molybdenum content.
- (2) No definite trend was present to show whether molybdenum alloyed through the core wire produced any different results than when alloyed through the flux. One set with the commercially melted rod gave slightly poorer results than its induction melted counterpart; the other set gave superior results.
- (3) Tests on the virgin armor indicated superior ballistic resistance to any of the welded samples. Tests taken with the specimen axis transverse to the rolling direction were decidedly inferior to those taken parallel.

4. Nature of Failure in Explosion Tested Samples

The progress of cracks in the explosion tested samples were traced as follows:

- (1) Initiation as minute fissures in the armor just at the interface about one-half way between the root and the back face.
- (2) Extension in both directions, towards the root and towards the back face, travelling mostly in the armor, but occasionally in the weld metal.
- (3) At a point beyond the root generally at the base of the shoulder pass on the face side, the crack turned out into the weld-metal and continued to the face. Travelling in the other direction, the crack also passed out

into the weld metal generally in the vicinity of the pass just below the shoulder bead.

- (4) Where the crack extended in the weld in some instances, it travelled for short distances along the hard interface zone which was found just on the fusion line. In general, however, the tendency appeared for the cracks to cross over, well into the softer weld metal.
- (5) These observations were consistent throughout the series and the nature of the failures could not be related to variations in the composition of the electrodes.

FUTURE WORK

While the preliminary results of this first investigation indicate the desirability of molybdenum additions to the austenitic 20 Cr-10 Ni type electrode, the present critical shortage of this element militates against its use in any substantial amounts. The establishment of some other method of minimizing sensitivity to root cracking therefore must be seriously considered.

One possibility appears to be the use of electrodes with high chromium to nickel ratios. Preliminary tests suggest that increasing the Cr/Ni ratio tends to lessen the degree of center root cracking.

In addition it appears essential to establish whether the type of ballistic failure encountered in this investigation is characteristic of armor weldments or is traceable to the particular type of armor employed.

The following further work has therefore been planned:

- (1) Investigation of the effect of variations in Cr/Ni ratio of electrodes combined with variations in molybdenum content. Testing procedures similar throughout to those described in this report will be employed excepting that tensile test samples will be selected in such a way as to avoid including weld metal from the shoulder beads of the test plates. In addition all-weld-metal tensile tests will be included to determine the effect on the physical properties of the weld metal alone.
- (2) Repetition of the first investigation by selecting at least two of the electrode compositions originally employed and preparing test plates from several other makes of homogeneous armor. Testing procedures similar to (1) above would be employed.

APPENDIX I

	<u>Page Number</u>
Table I - Analysis of Core Wire and Weld Metal	1
Table II - Sensitivity to Root Cracking. Critical Root Thickness	2
Table III- Frequency of Interface Cracking	3
Table IV - Tensile Test Data	4
Table V - Explosion Test Data	5

APPENDIX I - I

TABLE I
 ANALYSIS OF CORE WIRE AND WELD METAL⁽¹⁾⁽²⁾

SERIES NO.	COMPOSITION IDENTITY	HEAT NO.	MELTING PRACTICE	MATERIAL ⁽³⁾	C	MN	P	S	SI	CR	NI	MO	CR-NI RATIO
I	1.5 MN-0.0 MO	E 801	INDUCTION	CW	.087	1.45	.028	.016	.33	20.07	10.01	—	2.01
				WM	.100	1.54	.036	.009	.21	19.67	10.17	.07	1.93
	2.0 MN-0.0 MO	E 803	INDUCTION	CW	.089	1.90	.035	.012	.36	20.22	9.99	—	2.02
				WM	.102	2.15	.034	.019	.33	19.79	10.10	.07	1.96
	2.0 MN-0.0 MO-E	33005	ELECTRIC	CW	.071	1.82	.038	.015	.33	20.48	9.96	—	2.06
				WM	.077	1.90	.042	.017	.30	19.75	9.97	.07	1.98
	4.3 MN-0.0 MO	E 806	INDUCTION	CW	.083	4.11	.046	.011	.37	20.28	9.88	—	2.05
				WM	.100	4.47	.053	.008	.34	19.79	10.02	.08	1.97
II	2.0 MN-1.5 MO	E 809	INDUCTION	CW	.092	1.92	.034	.015	.39	20.26	9.92	1.62	2.04
				WM	.098	1.98	.035	.025	.31	19.66	10.08	1.59	1.95
	2.0 MN-(1.5MO)	E 804	INDUCTION	CW	.096	1.90	.036	.012	.39	20.04	9.72	—	2.06
				WM	.140	1.81	.033	.035	.34	19.06	9.70	1.44	1.97
	2.0 MN-(1.5MO)-E	33005	ELECTRIC	CW	.071	1.82	.033	.015	.33	20.48	9.96	—	2.06
				WM	.080	1.80	.044	.020	.32	19.29	9.79	1.65	1.97
	2.0 MN-3.0 MO	E 811	INDUCTION	CW	.091	1.94	.032	.012	.43	20.31	10.01	3.07	2.03
				WM	.100	2.09	.038	.014	.25	19.72	10.10	2.96	1.95
III	4.3 MN-1.5 MO	E 813	INDUCTION	CW	.083	4.27	.044	.012	.44	20.50	9.94	1.61	2.06
				WM	.096	4.56	.051	.010	.28	19.79	10.00	1.57	1.98
	4.3 MN-(1.5MO)	E 807	INDUCTION	CW	.084	4.10	.047	.016	.39	20.20	9.86	—	2.05
				WM	.138	4.37	.045	.028	.35	19.26	9.72	1.44	1.98
	4.3 MN-3.0 MO	E 815	INDUCTION	CW	.099	4.35	.045	.015	.42	20.32	9.95	3.00	2.04
				WM	.100	4.56	.049	.018	.25	19.79	10.12	2.88	1.96

(1) ANALYSIS OF TEST COUPON POURED DURING TEEMING OF HEAT.

(2) ANALYSIS OF WELD PAD PREPARED FROM 1/4" DIAMETER COATED ELECTRODES IN ACCORDANCE WITH PROCEDURE GIVEN IN BUREAU OF SHIPS SPECIFICATION 4624 (INT) APRIL 1, 1943.

(3) ABBREVIATIONS: CW - CORE WIRE, WM - WELD METAL

TABLE 11

SENSITIVITY TO ROOT CRACKING AS SHOWN BY CRITICAL ROOT THICKNESS

SERIES NO.	COMPOSITION IDENTITY	HEAT NO.	ROOT THICKNESS	APPEARANCE OF BEAD	ESTIMATED CRITICAL ROOT THICKNESS
			INCHES	(1)	INCHES
I	1.5 MN-0.0 MO	E 801	.250	N	.250 - .280
			.250	N	
			.250	P	
			.250	C	
			.220	C	
	2.0 MN-0.0 MO	E 803	.250	N	.250 - .280
			.250	N	
			.250	P	
			.250	P	
			.220	P	
	2.0 MN-0.0 MO-E	33005	.310	N	.250 - .260
			.250	N	
			.250	N	
			.250	N	
			.250	P	
			.250	P	
			.220	C	
	4.0 MN-0.0 MO	E 806	.250	N	.250 - .280
			.250	N	
			.250	P	
			.250	C	
			.170	C	
II	2.0 MN-1.5 MO	E 802	.250	N	.190 - .230
			.250	N	
			.190	P	
			.170	C	
	2.0 MN-(1.5 MO)	E 804	.230	N	.220 - .230
	2.0 MN-(1.5 MO)-E	33005	.250	N	UNDER .230
			.230	N	
	2.0 MN-3.0 MO	E 811	.250	N	.190 - .230
			.230	P	
III	4.3 MN-1.5 MO	E 813	.250	N	.220 - .250
			.220	P	
			.200	P	
			.190	C	
	4.3 MN-(1.5 MO)	E 807	.250	N	.200 - .220
			.220	N	
			.200	P	
	4.3 MN-3.0 MO	E 815	.230	N	.220 - .230
			.220	N	
			.190	P	

(1) ABBREVIATIONS; N - NOT CRACKED
P - PARTIALLY CRACKED
C - COMPLETELY CRACKED

APPENDIX I - 3

TABLE III

FREQUENCY OF INTERFACE CRACKING

<u>SERIES NO.</u>	<u>COMPOSITION IDENTITY</u>	<u>HEAT NO.</u>	<u>TOTAL NO. PLATES WELDED</u>	<u>NUMBER DEFECTIVE</u>	<u>REMARKS</u>
I	1.5 MN-0.0 MO	E 801	3	3	VERY NUMEROUS INTERFACE CRACKS
	2.0 MN-0.0 MO	E 803	3	2	NUMEROUS INTERFACE CRACKS
	2.0 MN-0.0 MO-E	33005	3	1	FEW INTERFACE CRACKS
	4.3 MN-0.0 MO	E 806	5	1**	ONE INTERFACE CRACK
II	2.0 MN-1.5 MO	E 809	2	0	NO INTERFACE CRACKS
	2.0 MN-(1.5 MO)	E 808	2	0	NO INTERFACE CRACKS
	2.0 MN-(1.5 MO)-E	33005	2	0	NO INTERFACE CRACKS
	2.0 MN-3.0 MO	E 811	2	0	NO INTERFACE CRACKS
III	4.3 MN-1.5 MO	E 813	2	0	NO INTERFACE CRACKS
	4.3 MN(1.5 MO)	E 807	2	0	NO INTERFACE CRACKS
	4.3 MN-3.0 MO	E 815	3	1	ONE SMALL INTERFACE CRACK

* THREE PLATES PREHEATED TO 550, 500 AND 650 F., RESPECTIVELY. PLATE PREHEATED TO 550 F. DID NOT DEVELOP INTERFACE CRACKS.

** ONE SMALL INTERFACE CRACK DISCOVERED IN ONE PLATE IN TENSILE TEST SAMPLE MACHINED FROM ROOT. SEE TABLE IV.

TABLE IV
TENSILE TEST DATA

SERIES NO.	COMPOSITION IDENTITY	HEAT NO.	SPECIMEN (1)	ULT. TENS. STR. PSI	.2% YLD. STR. PSI	ELONGATION - %			ROCK. HARD. RANGE OF SHOULDER BEADS	REMARKS FRACTURE PASSED THROUGH:
						IN 2" (3)	WIDEST (4)	NARROWEST (5)		
I	1.5 MN-0.0 MO	E801	F	60,500	-	4.3	-	12.0	35C-43C	SHOULDER WELD WELD (6)
			R	88,100	68,400	7.0	21.4	29.8		
			B	90,900	46,350	16.0	35.2	44.9		
	2.0 MN-0.0 MO	E803	F	84,800	57,000	9.0	13.4	21.4	93B-41C	SHOULDER WELD SHOULDER
			R	94,500	10,700	6.5	21.3	23.7		
			B	84,200	56,500	7.8	11.7	18.4		
	2.0 MN-0.0 MO-E 33005		F	69,000	-	5.2	6.0	13.4	97B-33C	{ INTERFACE CRACK IN UNTESTED SAMPLE } { INTERFACE CRACK IN UNTESTED SAMPLE } { INTERFACE CRACK IN UNTESTED SAMPLE }
			R	18,700	-	-	-	-		
			B	62,000	-	2.7	11.7	5.5		
	4.3 MN-0.0 MO	E806	F	93,000	57,050	15.0	20.3	41.3	92B-94B	WELD WELD INTERFACE
			R	102,300	72,500	10.3	27.8	28.3		
			B	92,300	56,600	14.0	21.5	40.3		
II	2.0 MN-1.5 MO	E809	F	96,600	61,950	12.0	23.2	31.6	89B-35C	WELD (6) INTERFACE AND WELD SHOULDER
			R	102,500	74,600	2.3	25.6	29.4		
			B	83,500	56,900	7.8	9.8	20.0		
	2.0 MN-(1.5 MO) E804		F	96,300	61,950	10.0	-	24.7	92B-27C	SHOULDER INTERFACE SHOULDER
			R	97,400	75,500	10.0	27.0	24.2		
			B	89,600	61,950	8.3	9.1	13.9		
	2.0 MN-(1.5MO)-E 33005		F	77,000	-	6.0	5.2	14.5	84B-38C	SHOULDER WELD WELD (6)
			R	106,500	-	6.5	27.6	25.8		
			B	96,000	-	13.0	30.7	19.6		
	2.0 MN-3.0 MO	E811	F	95,500	63,900	14.0	22.4	34.0	94B-96B	(DROKE IN ARMOR) SHOULDER
			R	93,300	50,300	-	(19.2)	(20.2)		
			B	90,300	62,600	9.0	9.9	18.3		
III	4.3 MN-1.5 MO	E813	F	91,300	67,600	6.5	10.2	13.6	91B-96B	INTERFACE WELD WELD
			R	92,600	76,300	11.8	27.8	27.0		
			D	95,600	50,300	13.2	25.5	33.3		
	4.3 MN-(1.5MO) E807		F	96,600	63,100	13.0	17.2	35.6	91B-96B	WELD WELD INTERFACE
			R	104,000	-	9.3	29.6	25.0		
			B	101,200	63,500	11.8	15.9	30.4		
	4.3 MN-3.0 MO	E815	F	98,100	64,500	13.3	16.2	34.7	92B-96B	WELD INTERFACE AND WELD WELD
			R	106,800	69,200	7.6	16.2	18.4		
			C	102,300	65,000	12.0	16.3	30.8		

- (1) F - SPECIMEN FROM FACE
R - SPECIMEN FROM ROOT
B - SPECIMEN FROM BACK
- (2) DETERMINED BY OFFSET METHOD FOR .2% GAUGE OF EQUAL TO AVERAGE WIDTH OF WELD METAL.

- (3) INCLUDED WELD METAL AND SOME PLATE METAL ON EITHER SIDE OF JOINT.
(4) ACROSS WIDEST PORTION OF WELD METAL.
(5) ACROSS NARROWEST PORTION OF WELD METAL.
(6) SHOULDER METAL REMOVED IN GRINDING PLATES TO SIZE.

APPENDIX I - 5

TABLE V.

EXPLOSION TEST DATA

SERIES NO.	COMPOSITION IDENTITY	HEAT NO.	SAMPLE NO.	EXPLO-SIVE CHARGE	BEND IN TESTED SPECIMEN	ESTIMATED BREAKING CHARGE	REMARKS
				GRAMS	ANGLE		
I	1.5 MN-0.0 MO	E 801	B4	75	8.0	78	UNBROKEN-LARGE INTERNAL CRACK BROKE
			B5	80	13.5		
	2.0 MN-0.0 MO	E 803	D5	75	6.0	80	UNBROKEN-INTERNAL CRACKS BROKE UNBROKEN-EXTERNAL CRACK BROKE BROKE
			DD2	80	8.0		
			DD3	80	10.0		
			DD4	85	9.5		
			D4	250	-		
	2.0 MN-0.0 MO-E 33005		R5	70	10.0	73	UNBROKEN-EXTERNAL CRACK UNBROKEN-SMALL INTERNAL CRACK BROKE BROKE
			RR3	70	6.0		
			R4	75	9.0		
			RR2	75	-		
	4.3 MN-0.0 MO	E 806	G5	75	6.5	83	UNBROKEN-EXT. & INT. CRACKS UNBROKEN-SMALL INT. CRACK BROKE BROKE BROKE
			GG2	80	8.0		
			GG4	85	9.5		
			GG3	90	9.5		
			G4	200	6.5		
II	2.0 MN-1.5 MO	E 809	J5	75	6.0	80	UNBROKEN-INTERNAL CRACKS BROKE UNBROKEN-EXT. & INT. CRACKS UNBROKEN-EXT. & INT. CRACKS BROKE
			JJ2	80	10.5		
			JJ3	80	7.5		
			JJ4	85	10.0		
	2.0 MN-(1.5MO)	E 804	J4	125	5.5	78	UNBROKEN-SMALL INT. CRACKS UNBROKEN-NO CRACKS BROKE BROKE BROKE
			E5	75	6.0		
			EE4	75	6.0		
			EE2	80	7.5		
			EE3	80	-		
	2.0 MN-(1.5 MO)-E 33005		E4	175	9.0	93	UNBROKEN-EXT. & INT. CRACKS UNBROKEN-EXT. & INT. CRACKS UNBROKEN-LARGE EXT. CRACK UNBROKEN-EXT. & INT. CRACKS BROKE
			S4	75	9.0		
			S5	80	9.5		
			SS2	85	7.5		
			SS4	90	11.0		
	2.0 MN-3.0 MO	E 811	SS3	95	8.5	75	UNBROKEN-LARGE INTERNAL CRACK UNBROKEN-NO CRACKS UNBROKEN-SMALL INTERNAL CRACKS BROKE BROKE
			L5	65	5.5		
			LL2	70	2.0		
			LL4	72	6.0		
			L4	75	5.5		
			LL3	80	10.5		

APPENDIX I - 6

TABLE V - (CONT.)

EXPLOSION TEST DATA

SERIES NO.	COMPOSITION IDENTITY	HEAT NO.	SAMPLE NO.	EXPLO-SIVE CHARGE	DEND IN TESTED SPECIMEN	ESTIMATED BREAKING CHARGE	REMARKS
III	4.3 MN-1.5 MO	E 813	N4	GRAMS 75	ANGLE 5.5	60	UNBROKEN- NO CRACKS
			N5	80	7.5		UNBROKEN- INTERNAL CRACKS
			NN4	80	6.5		DROKE
			NN3	85	7.5		DROKE
			NN2	90	7.5		DROKE
	4.3 MN-(1.5MO)	E 807	H4	50	3.5	63	UNBROKEN - NO CRACKS
			H5	65	6.0		UNBROKEN - SMALL INT. CRACKS
			HH2	80	8.0		UNBROKEN-EXT. & INT CRACKS
			HH4	80	5.5		UNBROKEN-SMALL EXTERNAL CRACK
			HH3	85	-		DROKE
	4.3 MN-3.0 MO	E 815	P5	70	5.5	73	UNBROKEN - NO CRACKS
			PP3	70	5.5		UNBROKEN -SMALL INT. CRACK
			PH	75	6.0		DROKE
			PP4	75	-		DROKE
			PP2	80	6.0		DROKE
ARMOR	TRANSVERSE (LONG AXIS RIGHT ANGLES TO ROLLING DIRECTION)	9-04474	AT3	150	14.0	225	UNBROKEN-SMALL EXT. CRACK
			AT4	200	20.0		UNBROKEN-LARGE EXT. CRACK
			AT5	250	22.0		DROKE
			AT2	300	-		DROKE
			AT1	500	-		DROKE
ARMOR	LONGITUDINAL (LONG AXIS PARALLEL TO ROLLING DIRECTION)	9-04474	A1	175	16.0	OVER 700	UNBROKEN-SMALL EXT. CRACK
			A2	225	19.0		UNBROKEN-LARGE EXT. CRACK
			A3	300	22.5		UNBROKEN-LARGE EXT. CRACK
			A4	500	33.0		UNBROKEN-SEVERELY CRACKED
			A5	700	34.0		UNBROKEN-SEVERELY CRACKED

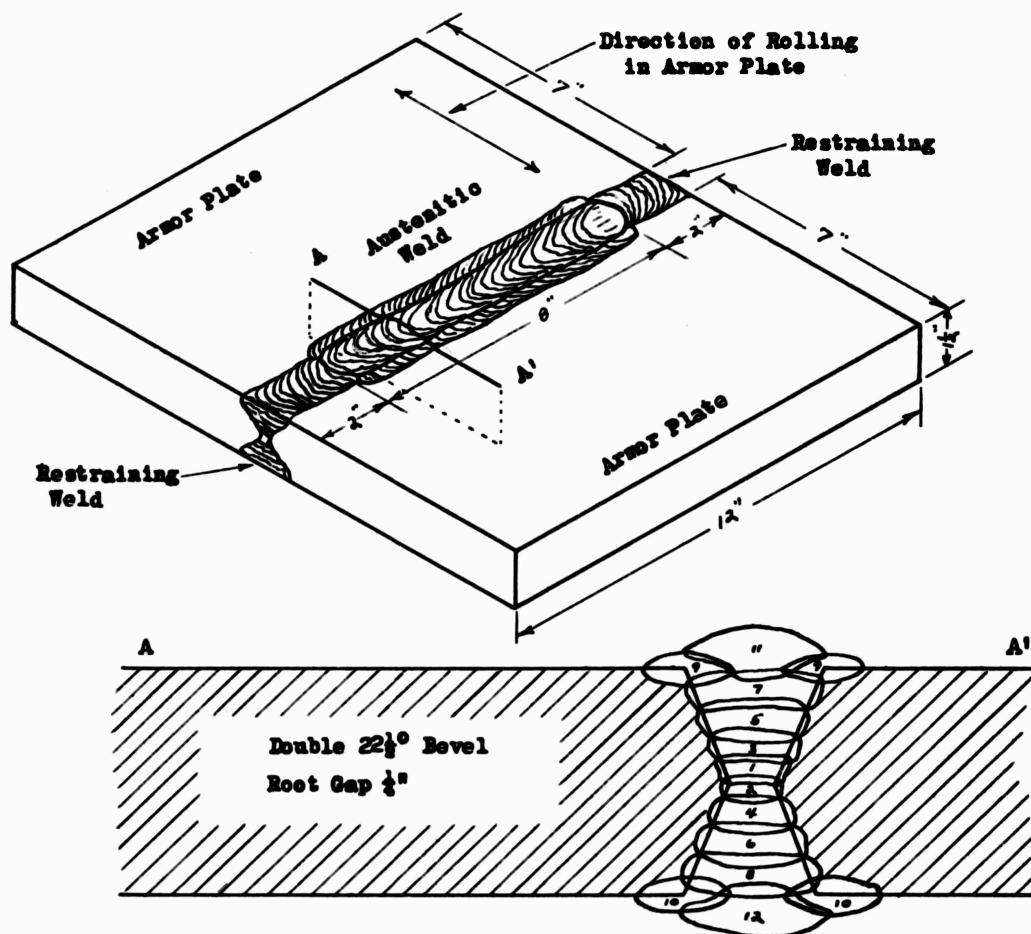
APPENDIX II

Drawings, Photographs and Photomicrographs.

Figures 1 to 18, inclusive.

Pages 1

to 12



WELDING PRACTICE

Clamped in restraining jig during entire welding operation, plus 24 hours.
Maximum interpass temperature 200° Fahrenheit.

Layer No.	Electrode Size	Amperage	Remarks
1	3/16" Diameter	160 - 190	Root bead - copper back-up used
2	3/16" "	170 - 200	
3	1/4" "	250 - 290	
4	1/4" "	250 - 290	
5	1/4" "	250 - 290	
6	1/4" "	250 - 290	
7	1/4" "	250 - 290	
8	1/4" "	250 - 290	
9	3/16" "	190 - 210	Shoulder beads
10	3/16" "	190 - 210	Shoulder beads
11	1/4" "	270 - 300	Crown bead
12	1/4" "	270 - 300	Crown bead

Fig. 1 Test Plate Design and Welding Practice

RUSTLESS IRON AND STEEL CORPORATION

Appendix II - 2

Preparation of Test Plate

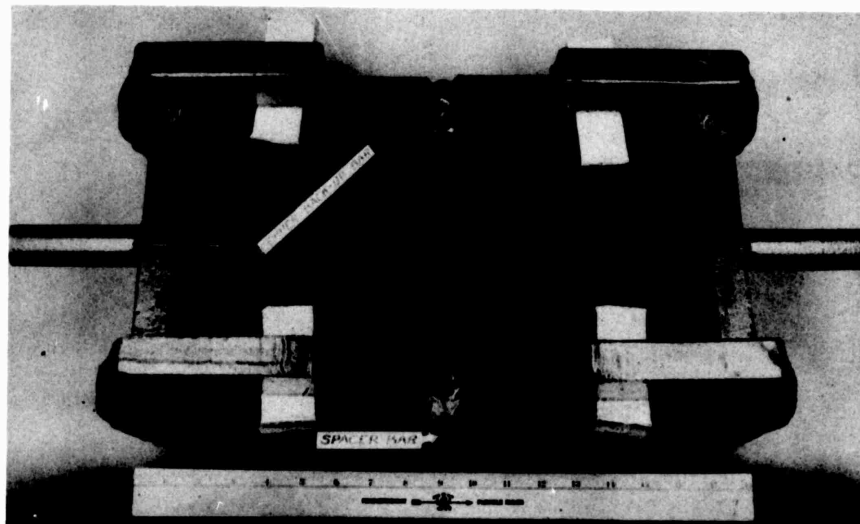


Fig. 2 Test Plate Clamped in Jig, Ready for Welding

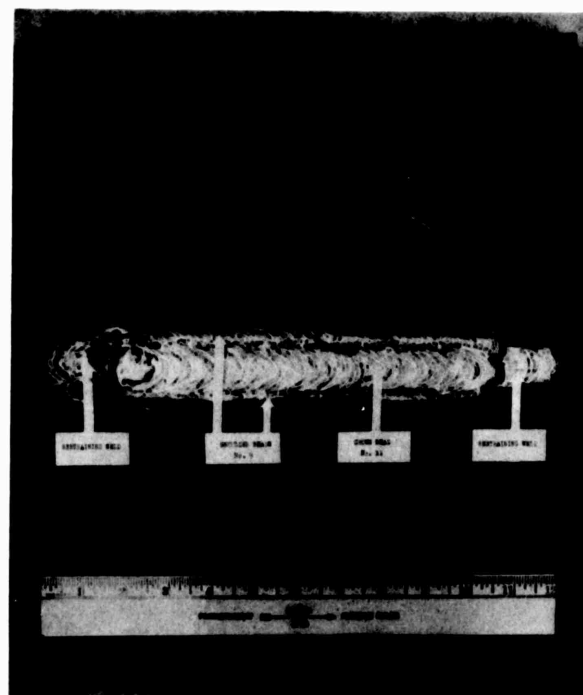


Fig. 3 Appearance of Welded Test Plate
After Removing from Jig

RUSTLESS IRON AND STEEL CORPORATION

Appendix II - 3

Determination of Sensitivity to Root Cracking

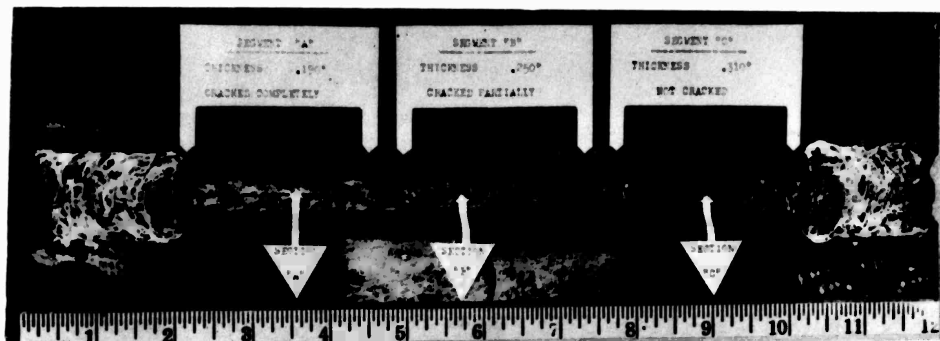


Fig. 4

Face Side

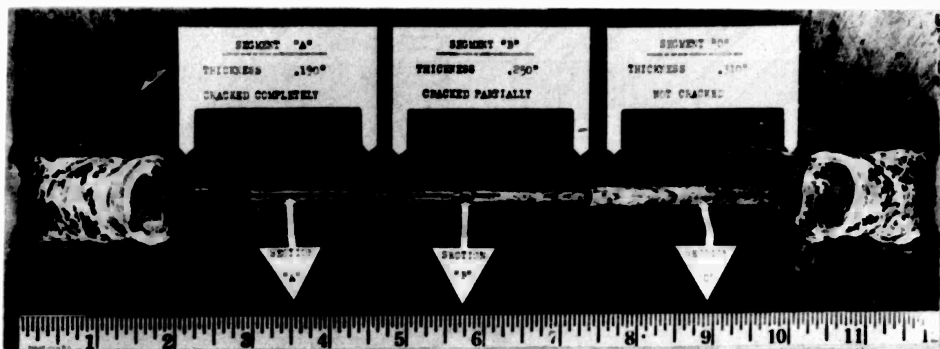


Fig. 5

Back Side

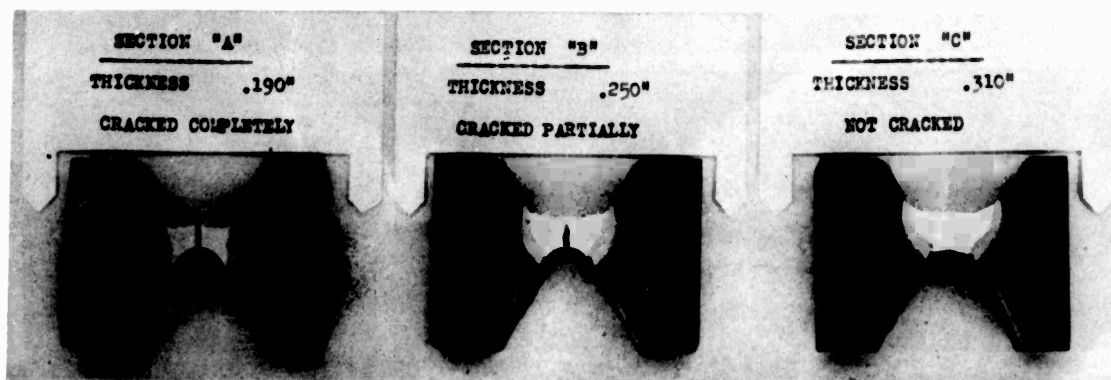


Fig. 6 Macro Etched Sections at Points Indicated in Figs. 4 and 5

Figs. 4, 5 and 6 Appearance of Root Pass with Beads of Three Thicknesses
Composition 2.0 Mn-0.0 Mo-E

RUSTLESS IRON AND STEEL CORPORATION

Appendix II - 4

Sectioning Test Plate and Macro Etch Testing

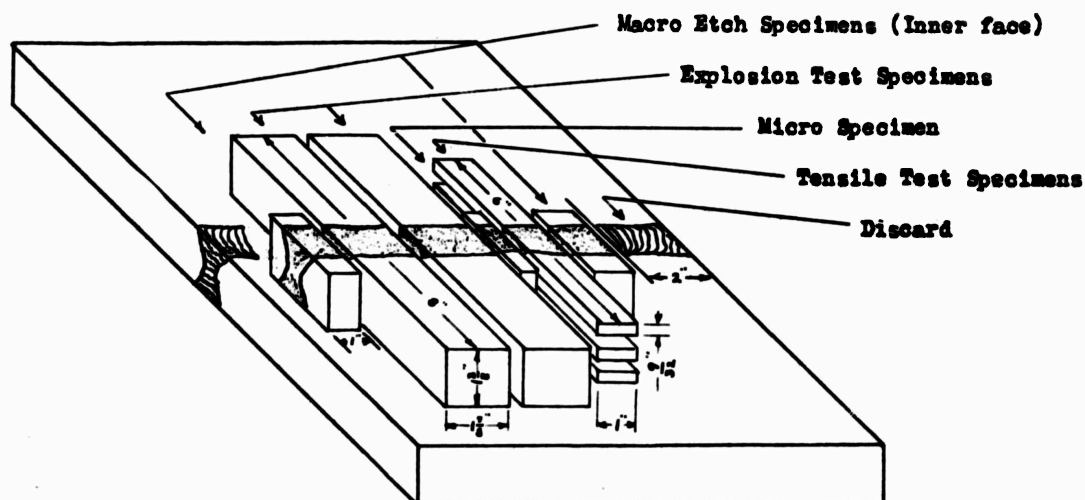


Fig. 7 Manner of Sectioning Test Plate for Test Specimens

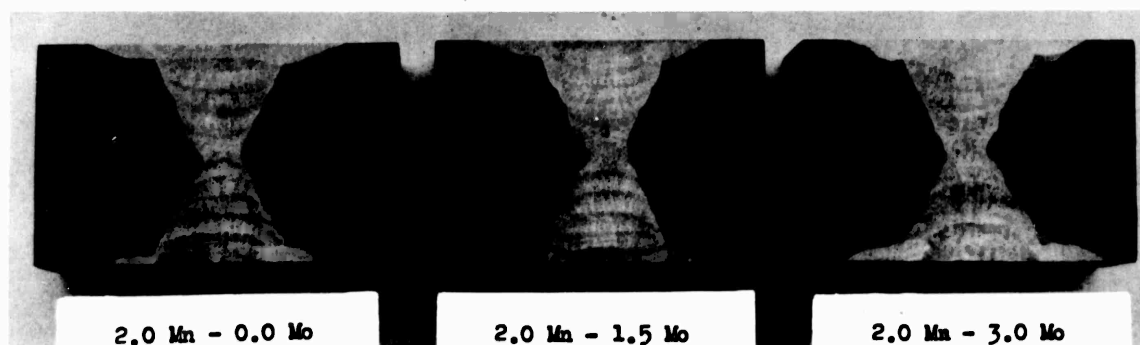
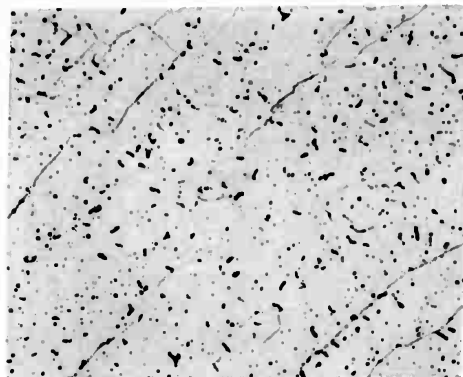


Fig. 8 Typical Macro Etched Samples from Series I, II and III

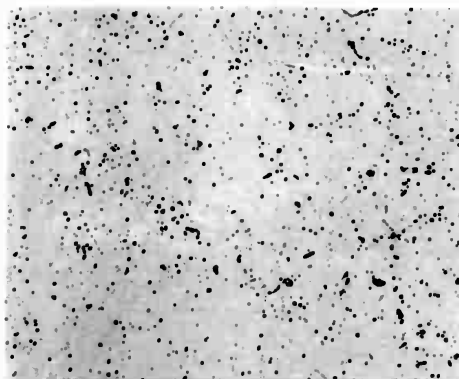
RUSTLESS IRON AND STEEL CORPORATION

Appendix II - 5

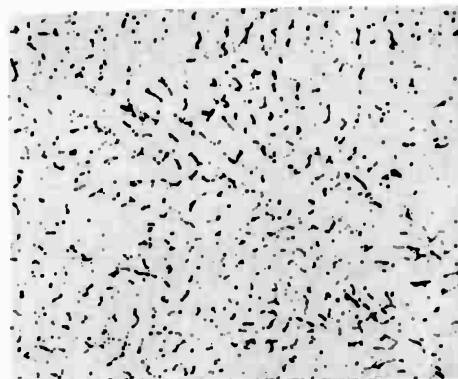
Microstructure in Root Pass, Series I



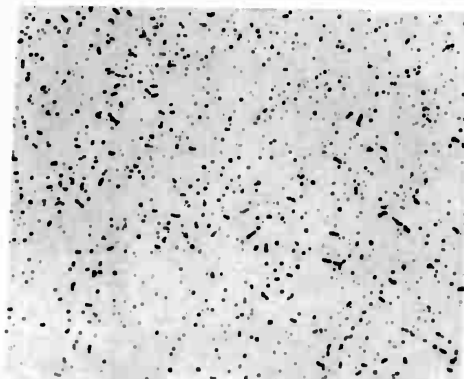
Composition 1.5 Mn-0.0 Mo



Composition 2.0 Mn-0.0 Mo



Composition 2.0 Mn-0.0 Mo-E



Composition 4.3 Mn-0.0 Mo

Fig. 9

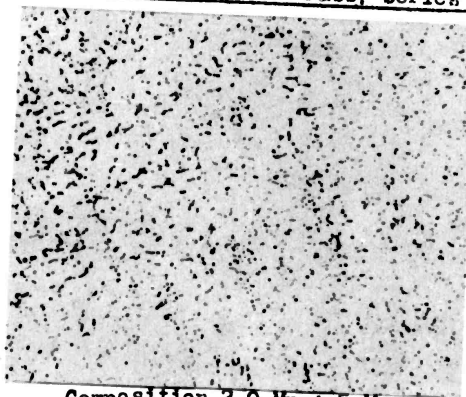
Microstructure of Weld Metal in Root Pass

X200

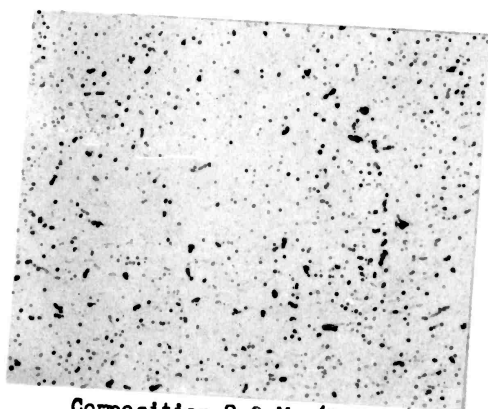
RUSTLESS IRON AND STEEL CORPORATION

Appendix II - b

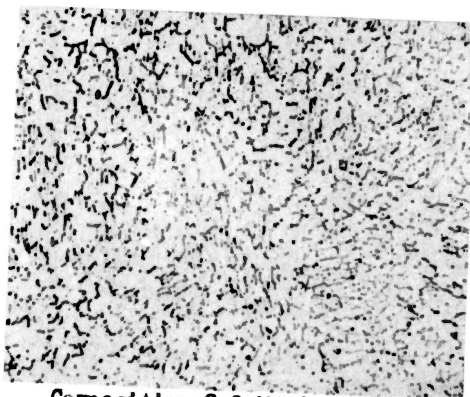
Microstructure in Root Pass, Series II



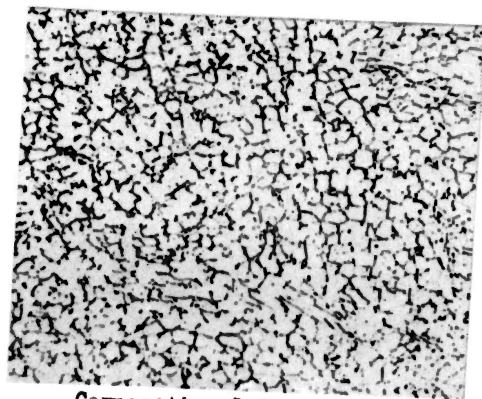
Composition 2.0 Mn-1.5 Mo



Composition 2.0 Mn-(1.5 Mo)



Composition 2.0 Mn-(1.5 Mo)-E



Composition 2.0 Mn-3.0 Mo

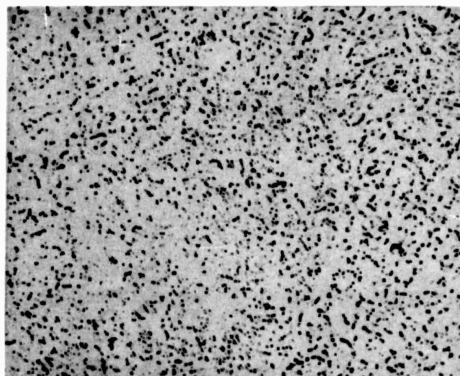
Fig. 10 Microstructure of Weld Metal in Root Pass

X200

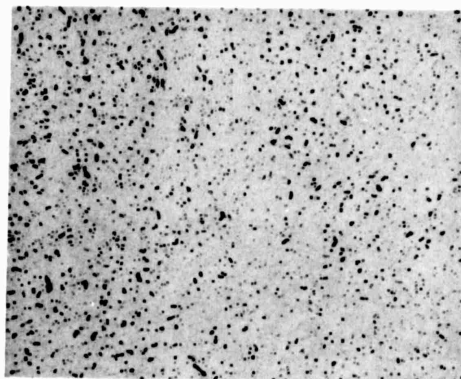
RUSTLESS IRON AND STEEL CORPORATION

Appendix II -7

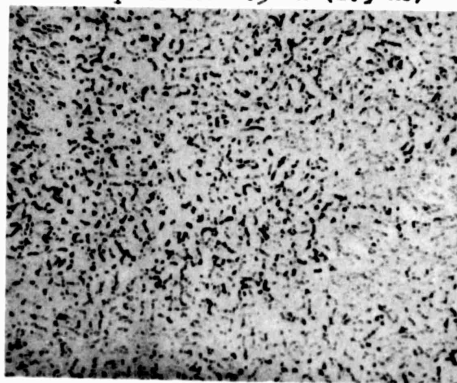
Microstructure in Root Pass, Series III



Composition 4.3 Mn-1.5 Mo



Composition 4.3 Mn-(1.5 Mo)



Composition 4.3 Mn-3.0 Mo

Fig. 11 Microstructure of Weld Metal in Root Pass X200

RUSTLESS IRON AND STEEL CORPORATION

Appendix II - 8

Microstructure at Fusion Line

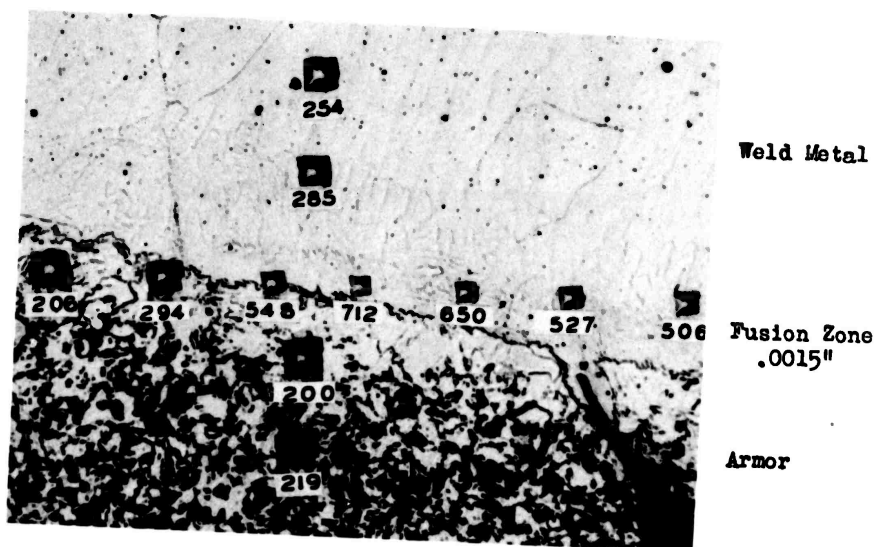


Fig. 12 Microstructure at fusion zone
Microhardness impressions with Eberbach
Tester
Composition 1.5 Mn-0.0 Mo X500

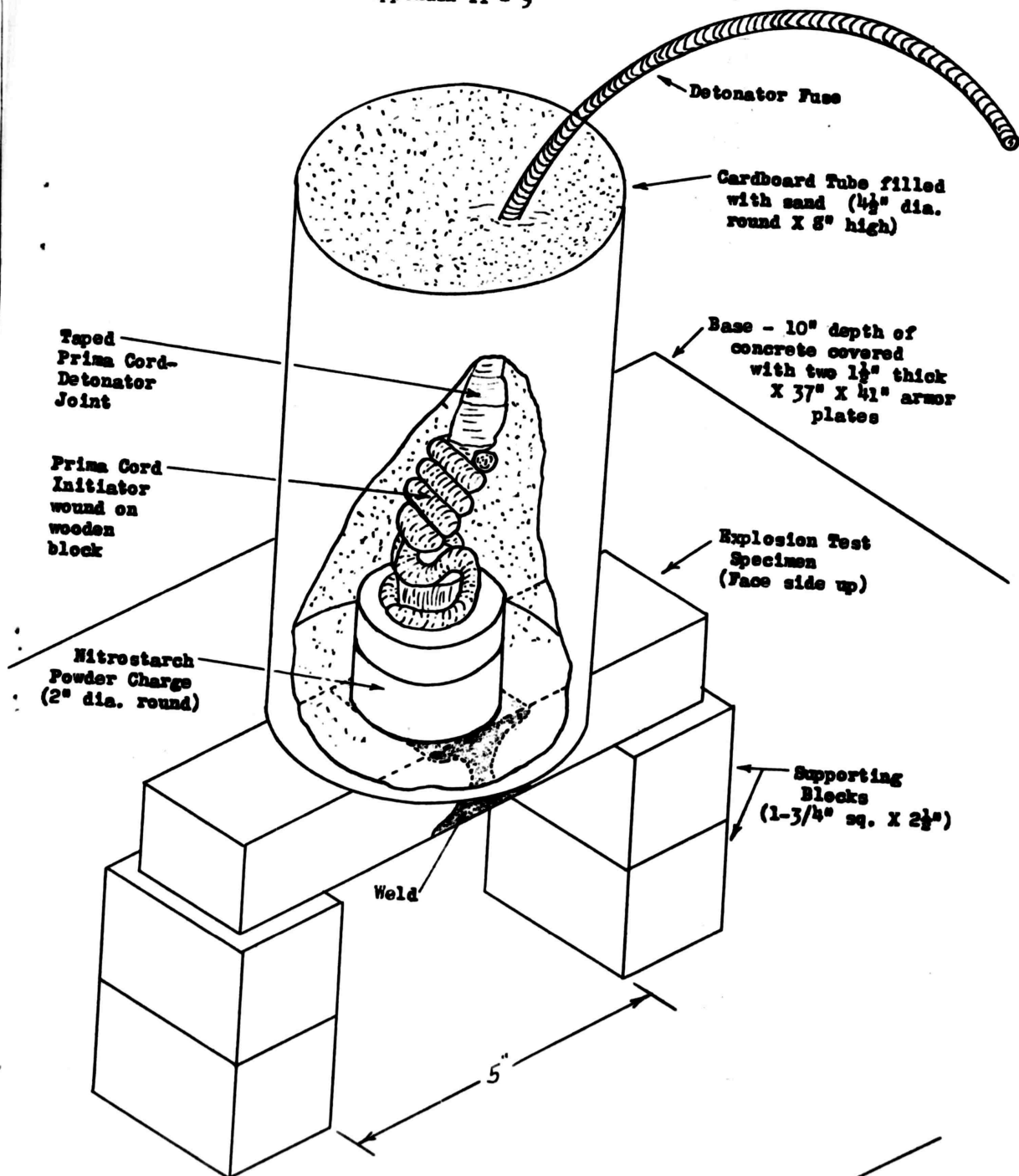
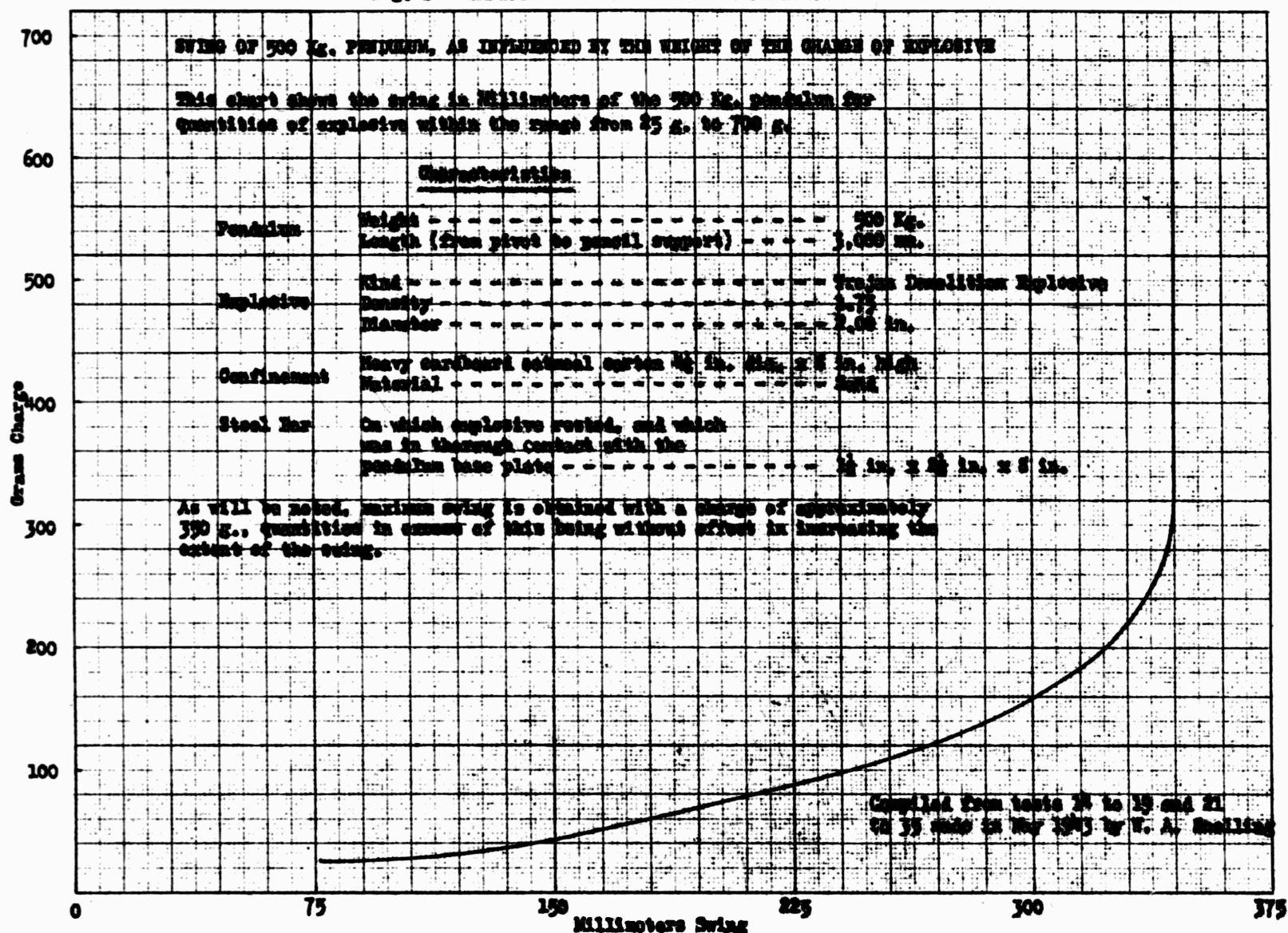


Fig. 13 Explosion Test Set-up

Fig. 14 EXPLOSION TESTING BALLISTIC PENDULUM



Appendix II - 11

Explosion Tested Samples

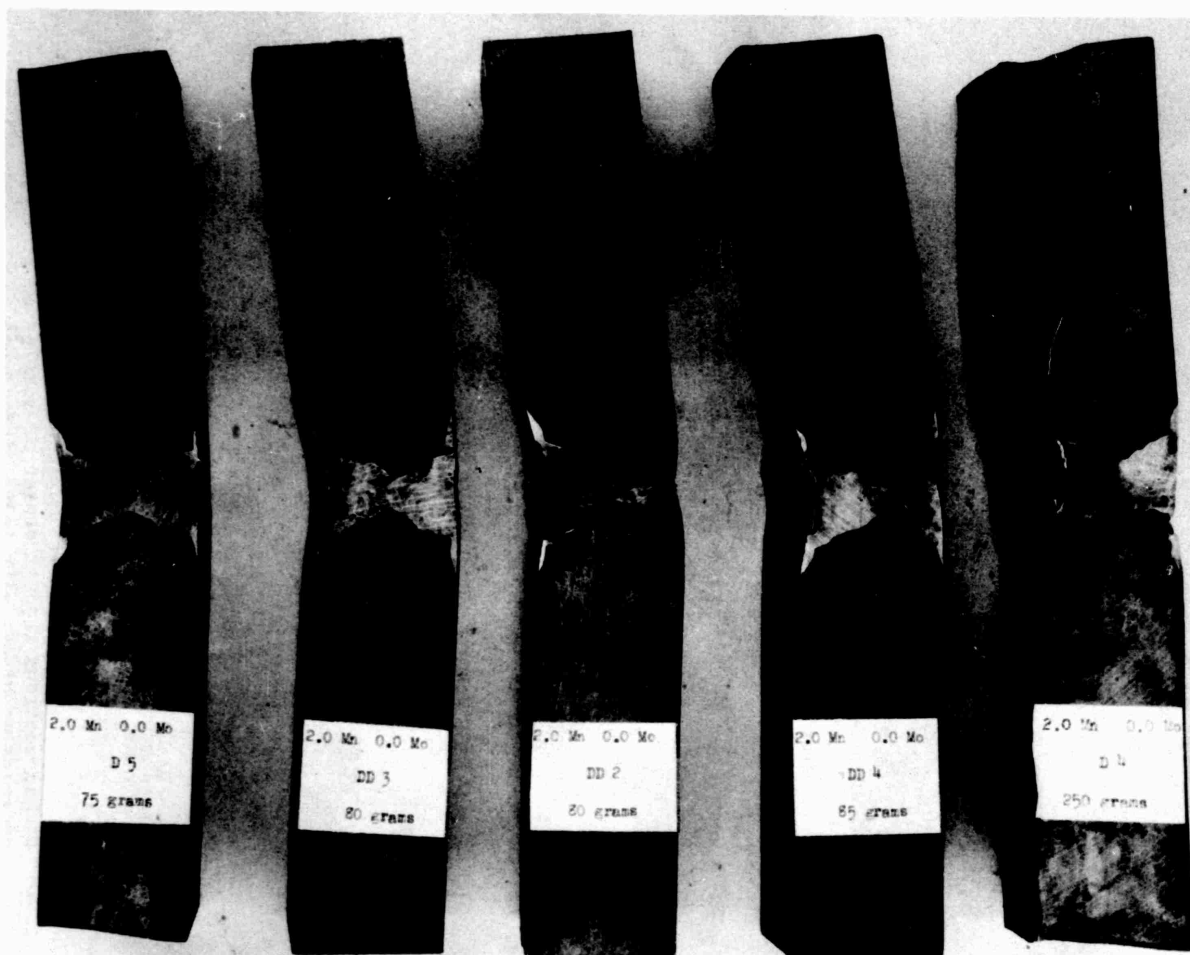


Fig. 15 Appearance of Explosion Tested Samples.

Composition 2.0 Mn-0.0 Mo.

X 3/4

RUSTLESS IRON AND STEEL CORPORATION

Appendix II - 12

Development of Cracks in Explosion Tested Samples

Composition 2.0 Mn - 1.5 Mo

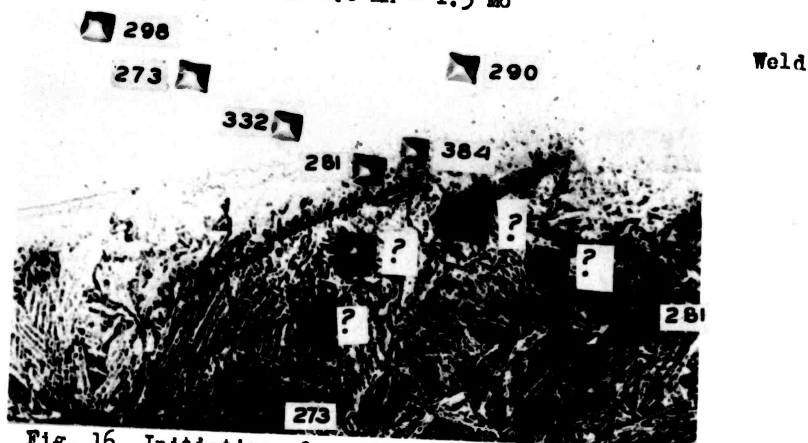


Fig. 16 Initiation of crack in armor X 500
Microhardness tests with Eberbach Tester



Fig. 17 Extension of crack along interface mostly in armor X 35

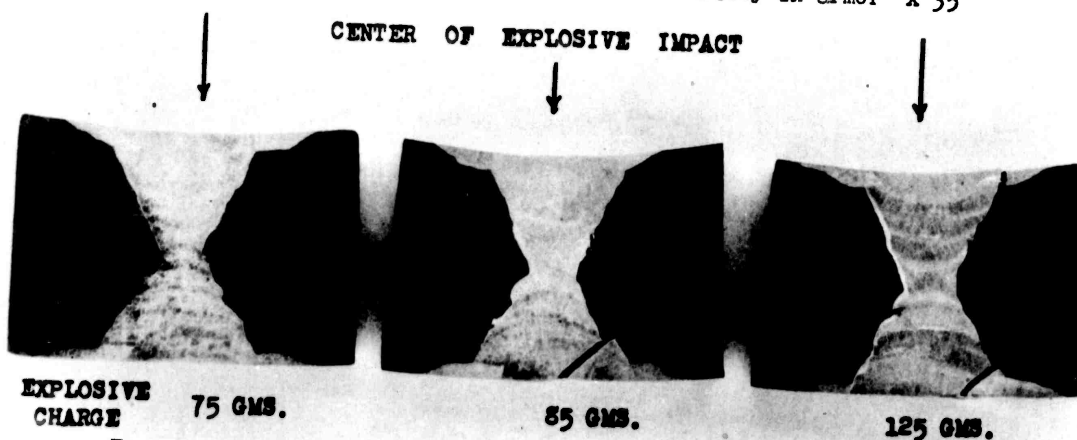


Fig. 18 Etched sections through center of samples showing final progress of cracks with increasing impact.

REEL - C

1 1 7 7

A.T.I.

2 7 7 1 0

TITLE: Development of Armor Welding Electrodes: Relation of The Composition of Austenitic (20 Cr-10 Ni) Electrode to the Physical and Ballistic Properties of *
AUTHOR(S): Feild, A. L.; Bloom, F. K.; Linnert, G. E.
ORIGINATING AGENCY: Rustless Iron and Steel Corp., Baltimore, Md.
PUBLISHED BY: Office of Scientific Research and Development, NDRC, Div 18

ATI-27710

REVISION
(None)

ORIG. AGENCY NO.

M-101

PUBLISHING AGENCY NO.

1838

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
July'43	Unclass.	U. S.	Eng.	41	photos, tables, diagrs.

ABSTRACT: A study was made of the effect of variations in the composition of austenite 20 Cr-10 Ni type electrodes on the properties of restrained armor weldments. Restrained double bevel armor joints were welded with 20-10 electrodes having variation in manganese content of 1.5, 2.0, and 4.3% combined with molybdenum content variations of 0, 1.5, and 3%. Testing included determination of sensitivity to center root bead cracking, interface cracking, as well as X-ray, macro etch and metallographic examinations. Physical and ballistic properties were determined by tensile tests and a special explosion test. High manganese contents combined with the use of some molybdenum are believed to represent the best electrode combination. Ballistic properties could not be related to composition, and no difference was observed for molybdenum added through the electrode coating or through the core wire.

* Armor Weldments (OD-38-2)

DISTRIBUTION: Copies of this report obtainable from Air Documents Division; Attn: MCIDXD

DIVISION: Ordnance and Armament (22)
SECTION: Armor (5)

SUBJECT HEADINGS: Electrodes, Welding (31497.9); Armor plate - Weldability (11520)

ATI SHEET NO.: R-22-5-9

Air Documents Division, Intelligence Department
Air Materiel Command

AIR TECHNICAL INDEX

Wright-Patterson Air Force Base
Dayton, Ohio